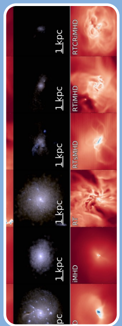
Dwarf galaxies beyond supernova feedback

Radiation, magnetic fields and cosmic rays

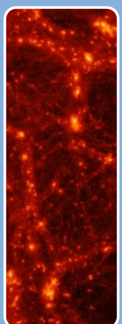
S. Martin-Alvarez with D. Sijacki, M. Haehnelt, et al.

Simulation suite



- We study the effect of frequently unincluded additional physics in galaxy formation.
- 18 runs featuring different physics.
- Build-up from DM-only to radiative transfer (RT), magnetohydrodynamics (MHD) and cosmic rays (CR).

Simulation



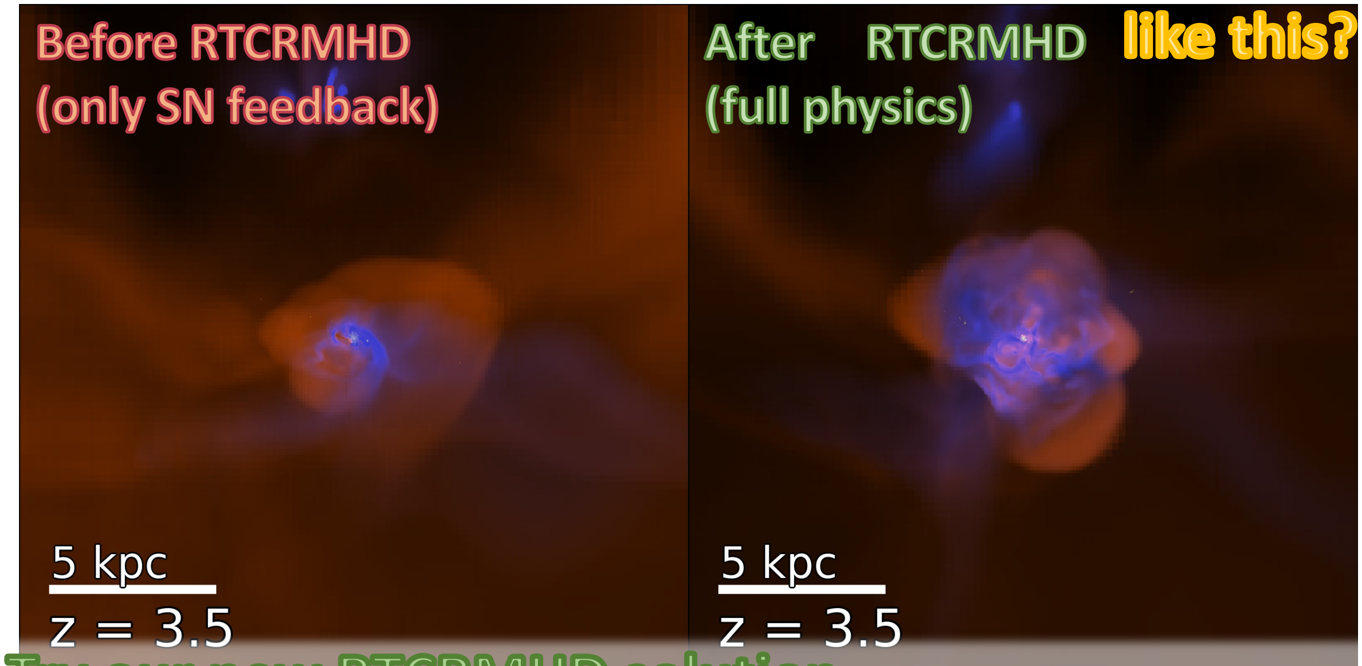
- Galaxy mass: $10^7\ M_{\odot}$ at $z \sim 3.5$.
- Box size: 14.7 Mpc.
- Cell resolution: 5 pc.
- Particle resolution: 1500 $M_{\odot}$.
- Planck cosmology: Ade+2016.

RT, CR and MHD

- Mag. fields injected by SN feedback: 0.01 E_{SN}.
- RT: configuration as for SPHINX simulations (Rosdahl+2017)
- CR injected by SN feedback (0.10 E_{SN}), cosmic ray streaming + diffusion ($\kappa = 3{\times}10^{28}\ cm^2/s$).

Are you tired of your stellar feedback not producing your desired results?

Do you want your galaxies to look like this?



Try our new RTCRMHD solution

Guaranteed results by the end of your simulation!

Ingredients: extracted from Martin-Alvarez et al. (in prep). **Made in DiRAC, COSMA7 UK.**

Use by: see reverse of slides. **Disclaimer:** results may vary according to stellar mass. Please consult your local numerical expert before running your simulations. The addition of additional physics may lead to other undesired side effects

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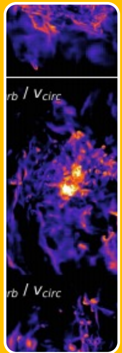
Stellar mass – Halo mass relation

First simulations of dwarf galaxies with radiation, magnetic fields, and cosmic rays

Different Physics



- **MHD:** initial boost in star formation.
- **RT:** delays star formation, but positive feedback effect on stellar mass.
- **CR:** reduces the stellar mass formed.

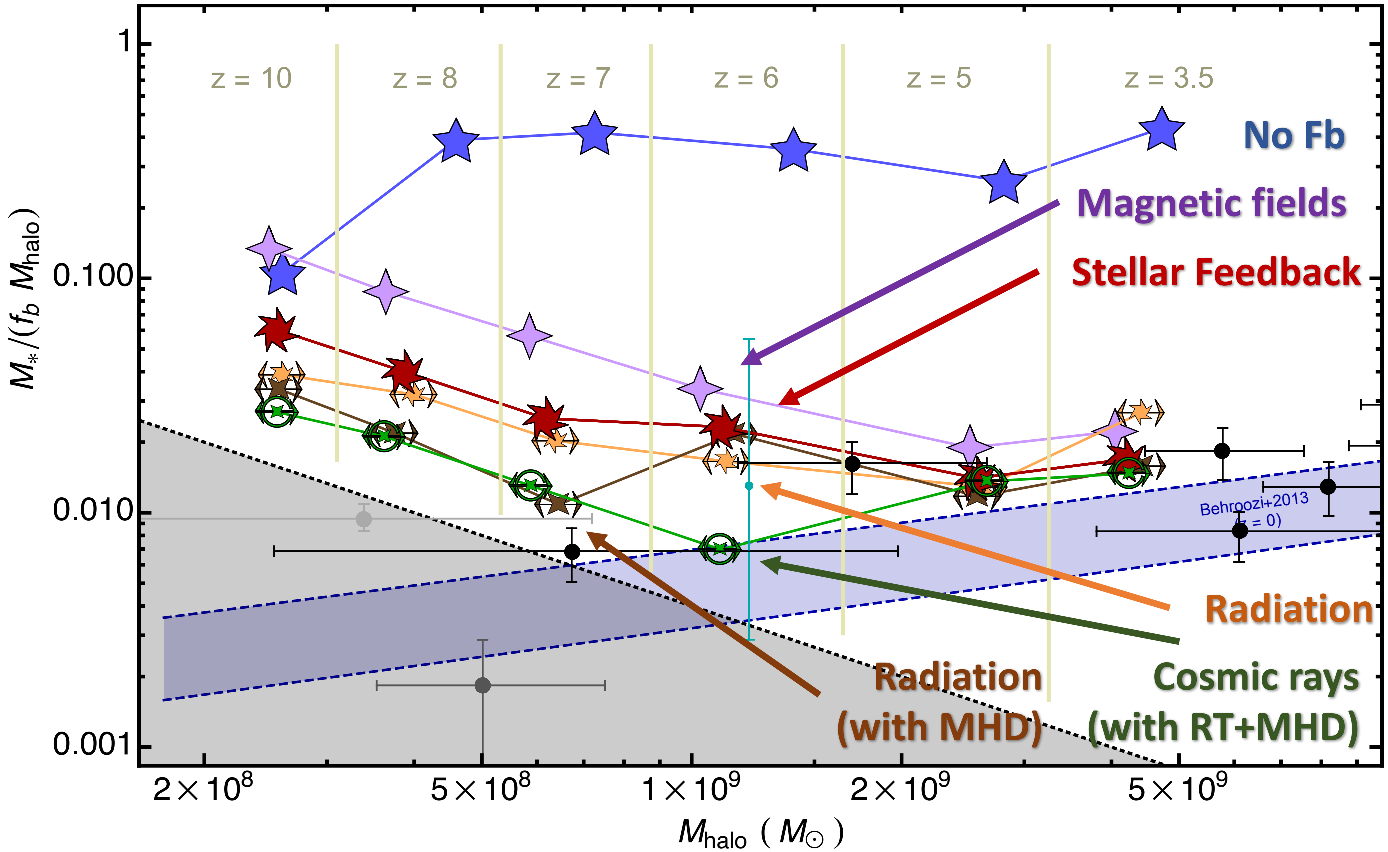
Physics Combinations

- RT+MHD: complex, non-linear interaction. Simulations required to understand the role of each physical component.
- RTCRMHD: the effect of cosmic rays accumulates on top of RT+MHD.

Results Comparison

- All simulations compare well with Behroozi+2013 extrapolation.
- RTCRMHD compares well with Read+2017 from z < 7.
- RTCRMHD reduce stellar mass within the results of SPHINX (cyan point; Rosdahl+2017): realistic reionization.

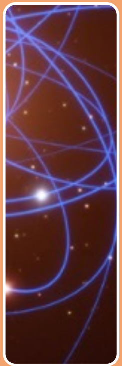
Include cosmic rays and radiation in your simulations: it will reduce your stellar mass at high redshift!



Mass-Size stellar relation

First simulations of dwarf galaxies with radiation, magnetic fields, and cosmic rays

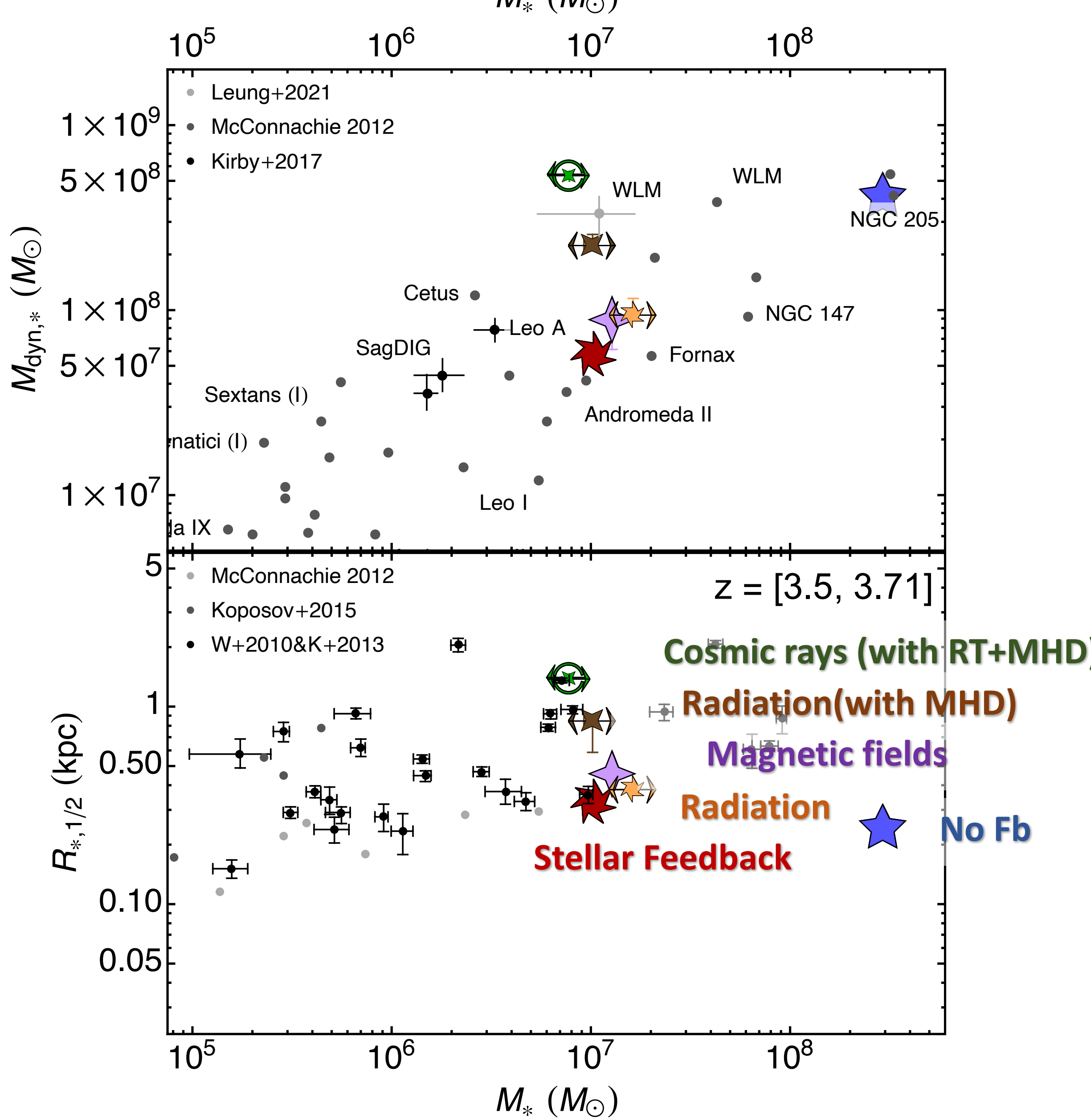
Dynamical vs stellar mass



- All RT, CR and MHD increase dynamical mass. Their effects accumulate.
- Simulations compare well with observations. Our RTCRMHD run in particular is a good match to more detailed studies by Kirby+2017 and Leung+2021.

Size vs Mass relation

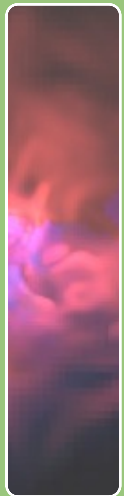
- RT and MHD independently have minor effect on half-mass radius.
- As for dynamical mass; RT+MHD and CR increase half-mass radius.
- Including additional physics yields spread that better matches observational spread of sizes.



Conclusions

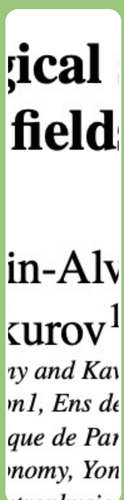
First simulations of dwarf galaxies with radiation, magnetic fields, and cosmic rays

Results presented here



- Additional physics lead to the same final stellar mass. But affect the high redshift evolution.
- Additional physics lead to more extended galaxies.
- Magnetic fields have secondary effects independently, but boost the impact of radiation.
- Radiation and cosmic rays are essential for dwarf galaxy formation.

Interested? Find out more!



- Upcoming paper, soon in the arXiv!
- 12 more simulations exploring different physics combinations, no-streaming cosmic rays, different star formation prescriptons, etc.
- Explore the effect of RTCRMHD on galaxy outflows and inflows.
- Studies of other components such as gas and HI. Review additional relations, metal enrichment, and much more!

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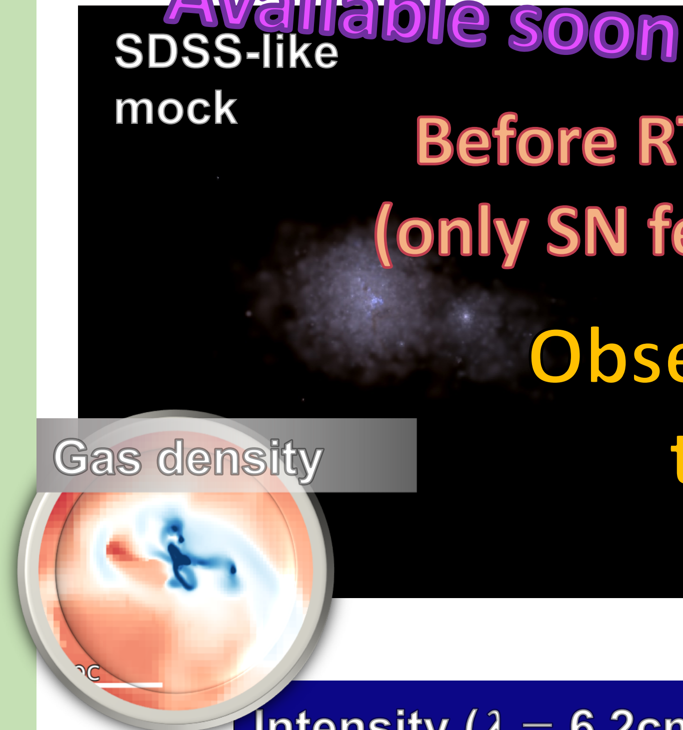
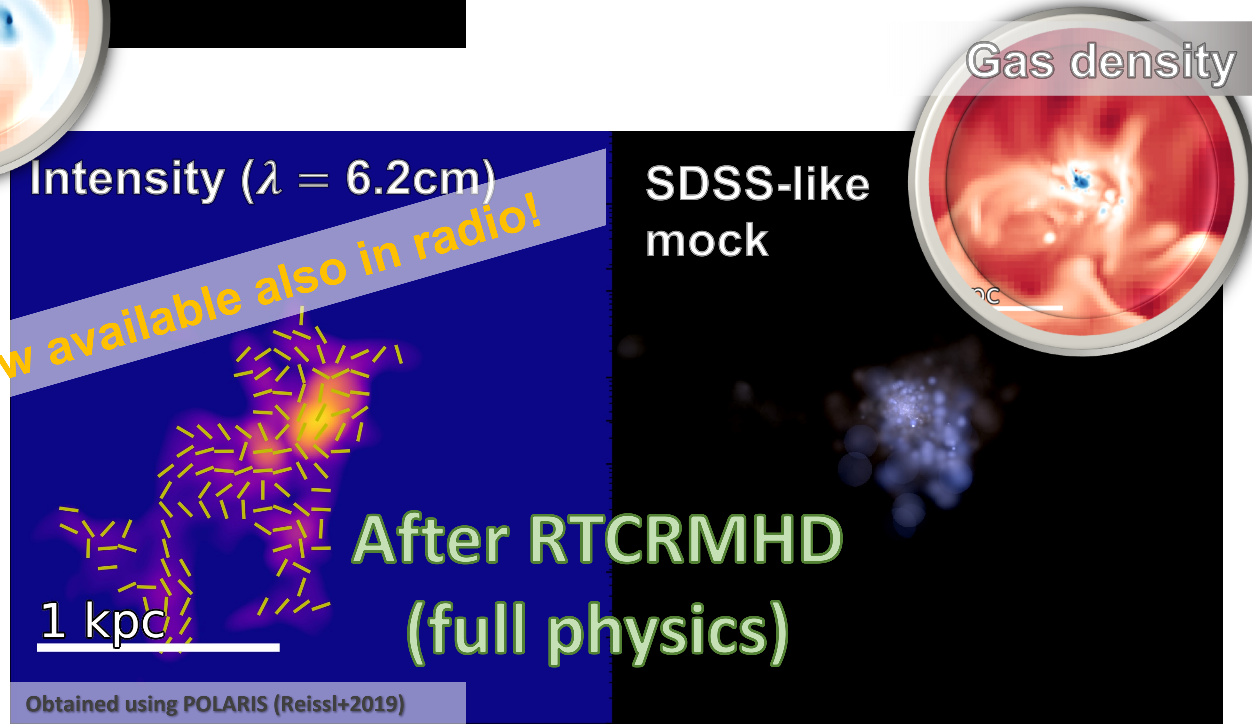
Available soon at your closest arXiv!



Before RTCRMHD (only SN feedback)

Observable results within the first Hubble time!



Now available also in radio!

After RTCRMHD (full physics)